New Non-Destructive Testing Tool for Steels Developed

SQUID Microscopy Used to Detect Plastic Deformation

A research team led by Bill Morris and John Clarke has made a major breakthrough in the non-destructive evaluation (NDE) of steels. Using a recently developed "SQUID microscope" that is capable of detecting changes in magnetization with high sensitivity and spatial resolution, they have used magnetic imaging to detect local plastic deformation non-destructively.

Magnetic measurement techniques for the non-destructive evaluation, inspection and detection of gross defects such as surface and sub-surface cracks in metals are well established. Some techniques, such as magnetic particle inspection, have been in routine use since the early 1900s. However, the magnetic measurement methods used to date for NDE have poor spatial resolution. There is a need to develop NDE tools that can detect local plastic deformation and the damage that precedes crack formation through fatigue. These tools would be used to examine ferromagnetic materials such as the steels used in nuclear pressure vessels, ship hulls and other critical structures to insure safety, as well as for on-line quality control in the manufacture of formed parts.

The MSD team built such a tool by adapting a recently developed magnetic "microscope" for use with metallurgical specimens. The microscope (see figure) uses a Superconducting Quantum Interference Device (SQUID)—an ultrasensitive detector of magnetic field—and is capable of detecting changes in magnetic field in the picotesla range with a spatial resolution of 100 micrometers. In "proof of principle" experiments the team used the SQUID microscope to detect plastic deformation by measuring the magnetic consequences of the microstructural changes it induced.

It is well known that plastic deformation of metals such as mild steel increases the density of dislocations within them. The increase in dislocation density hardens the material. The dislocations also interact with magnetic domain walls and, therefore, change the response of the steel to magnetic fields. To investigate whether these effects could be exploited to detect plastic deformation with magnetic techniques, the MSD team produced inhomogeneous deformation in a sample of annealed 1018 steel by rolling it to flatten a “hump” in the center of the specimen (see figure). The sample was magnetized in a 50 millitesla field for one minute, then scanned with the SQUID microscope to map out the remanent magnetization field at the surface. The SQUID map showed a pronounced “hump” in the remanent magnetization field, which resembled the physical hump in the specimen that was removed by plastic deformation. A map of the local hardness of the specimen was also measured. As shown in the figure, the hardness map mimics the remanent magnetization. The hardness is known to be proportional to the square root of the dislocation density; these results suggest that the remanent magnetization has the same dependence. These data also confirm the expectation that the ability of dislocations to pin (that is, immobilize) domain walls makes it possible to reveal the location and severity of plastic deformation through the magnetic observation of the dislocations it produces. In a parallel experiment the team induced an inhomogeneous strain of up to 10% in a tensile specimen and found, again, that the location and severity of the deformation were reflected in the remanent magnetization field measured by the SQUID microscope.

The team is currently working to refine the quantitative accuracy of the technique. They have begun a specific study of specimens subjected to known tensile strain to investigate whether the magnetization and hardness can be precisely related to it.

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T. J. Shaw, J. W. Chan, S. H. Kang, R. McDermott, J. W. Morris Jr., and J. Clarke, *Acta Materialia* **48**, 2655 ((2000).